

FEASIBILITY OF COLD WEATHER EARTHWORK

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by
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and
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Joint
Highway
Research
Project

PURDUE UNIVERSITY
LAFAYETTE INDIANA

Technical Paper
FEASIBILITY OF COLD WEATHER EARTHWORK

To: G. A. Leonards, Director
Joint Highway Research Project

February 15, 1968

From: H. L. Michael, Associate Director
Joint Highway Research Project

File No: 6-14-8

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Attached is a Technical Paper entitled "Feasibility of Cold Weather Earthwork" by C. W. Lovell, Jr. and A. M. Osborne. The content of this paper is primarily from the research report previously presented to the Advisory Board on the research project of similar title performed with financing from the Project.

The paper was presented at the 1968 Annual Meeting of the Highway Research Board and is scheduled to be published by that organization. The paper is presented to the Board for information and for approval of such publication.

Respectfully submitted,

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ABSTRACT

Most earthwork operations are more costly in the cold season than in the warm one. However, the benefits of keeping construction forces and equipment more continuously operative, plus those of advancing the completion date of a modern and more safe facility, may more than compensate for the increase in unit costs.

The cold weather earthwork experience of the northern states of the United States, the provinces of Canada, and the Scandinavian countries has been studied in the literature and by brief questionnaires. This effort has served to define, (a) the manner in which the winter weather and soil conditions tend to restrict the length of the construction season, (b) the designs and construction practices which have been employed to cope with the winter conditions, and (c) an estimate of the relative unit costs for various winter operations.

The advantages of cold weather earthwork have been defined in a simple linear economic model. An assessment of deterrents and benefits leads to the conclusion that cold weather earthwork is economically, as well as technically, feasible on many highway projects in the frost area of North America.

INTRODUCTION

Until a few decades ago, cold weather earthwork¹ was strictly avoided in highway construction. The requisite technology was recognized to be more complex and costly in the winter, and this factor was presumed to override the benefits that could be derived from earlier completion dates, continuous use of construction forces and equipment, and the like.

As the demand for new highway facilities accelerated, some penetrations into the traditional cold weather shutdown were accomplished. These developments have been concentrated in the cold regions, where the long duration of the poor weather has the most restrictive influence. However, the feasibility of "stretching" the construction season is also of growing interest where the winters are relatively mild.

In long range and total perspective, the need is for development of design and construction technology which will permit year-round earthwork operations in all climates and under almost every meteorological variation.

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1. The term "earthwork" is used in a comprehensive manner to include any excavation, handling, placement, or compaction operation with any "earthen" material...soil, rock, peat.

COLD WEATHER EFFECTS

On Workers and Equipment

The U.S. Army (3)¹ reports that the elements which govern the comfort, and subsequently the efficiency, of workmen are air temperature, wind velocity and relative humidity. Air temperature and wind velocity are combined in a "windchill" index, shown in Figure 1 for dry, shaded conditions.

Records of wind velocity and air temperature are of course available from numerous weather stations, and the windchill may be suitably predicted for any desired geographic location. Figure 2 is a sample prediction for four points in Indiana. In this plot, the relative occurrence of the "very cold" windchill is illustrated.

Data from a survey of the experience of Swedish contractors and engineers (2, 13) relate the efficiency of construction workers to the factors of air temperature, light, and precipitation. The operational efficiency of excavation and hauling equipment is also rated with respect to these three factors.

Cold temperatures can effectively immobilize construction equipment unless preventative maintenance is employed (3, 10). At very low temperatures, say below - 20° F, very intensive effort is required.

As indicated in the following section, winter activities may include ripping frozen soil crusts, breaking down frozen chunks of material, moving over surfaces of relatively low mobility, and other significant difficulties.

1. Numerals refer to items listed in the Bibliography.

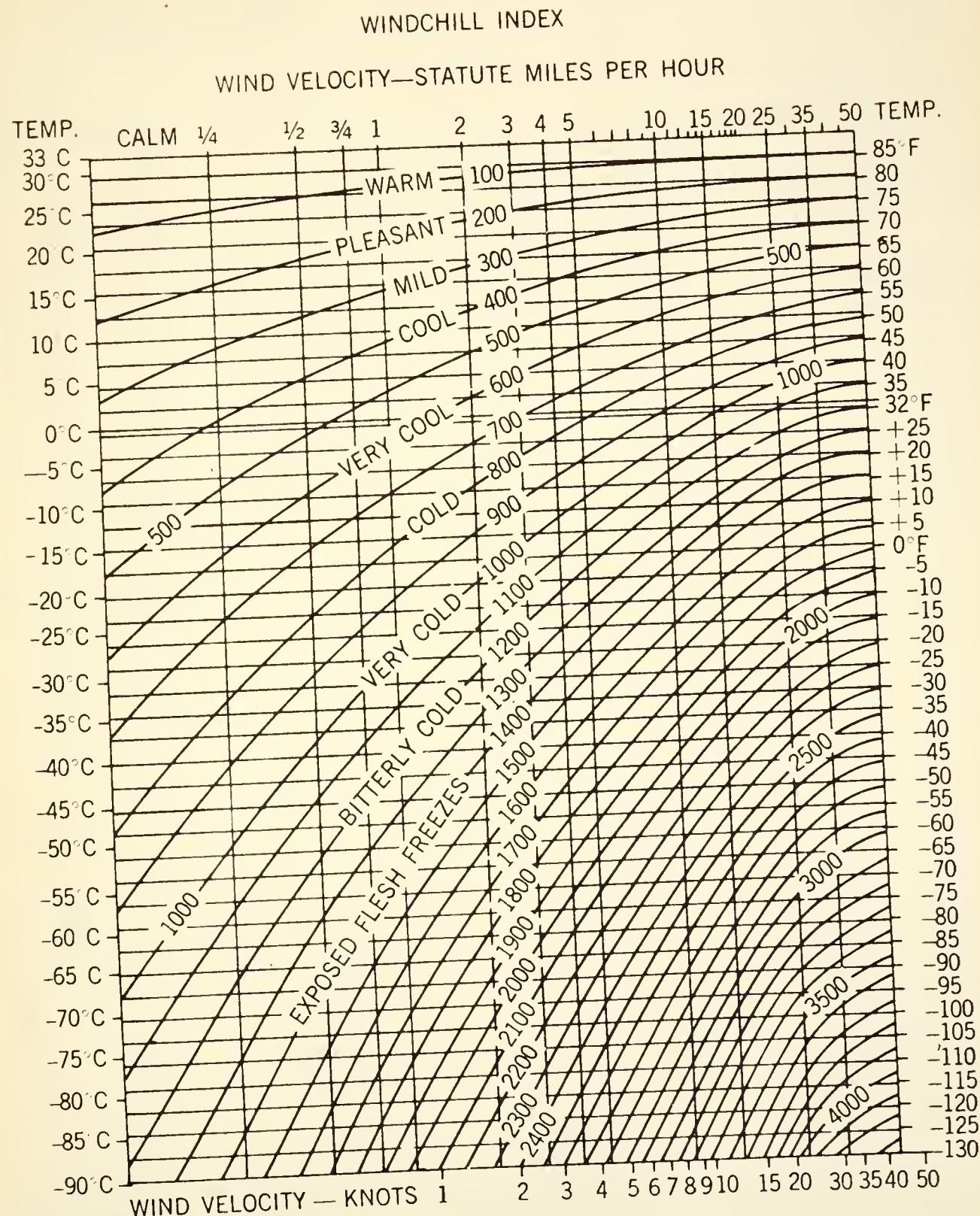


FIGURE I. GRAPH OF WINDCHILL RELATED TO TEMPERATURE AND SURFACE-WIND VELOCITY (FROM 3)

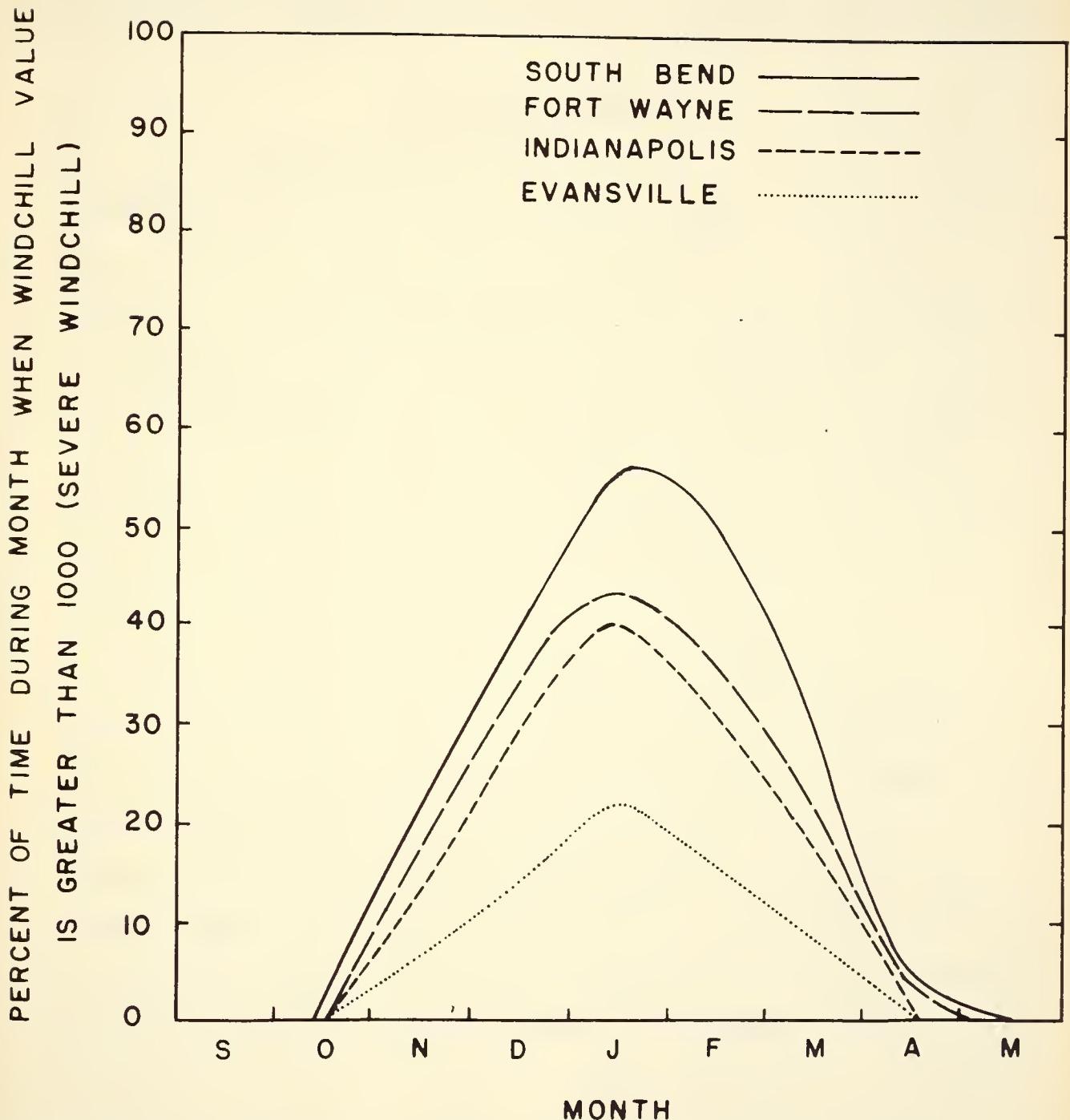


FIGURE 2. PERCENT OF TIME WHEN SEVERE WINDCHILL OCCURS AT SELECTED INDIANA WEATHER STATIONS

However, when the reduction in worker and equipment efficiency is examined, on paper, for a location like northern Indiana, values of the order of only 10 to 20% are obtained.

On Earthen Materials

The most dramatic effect is the production of a surficial zone in which some of the water is frozen. As ground temperatures are lowered below the value of initial freezing, additional portions of the pore water are changed to ice and the earthen material becomes stronger (7). The availability and transmissibility of water (8) are the keys to the character of the frozen ground, as well as to its condition during thaw. Concomitant with the cold weather are reduced evaporation rates and, sometimes, increased precipitation. In the southern U.S., frost is not a major problem, but heavy winter and spring rains cause suspension of work operations (13).

Soil is not usually placed or compacted in a partially frozen condition, but compaction of cold (yet unfrozen) material is feasible. Limited data on low temperature compaction (6) show that in general the maximum unit weight is decreased and the optimum water content is increased, relative to compaction at normal construction season temperatures. However, the changes are minor. Work at Purdue University with both sand and silty clay showed no systematic temperature dependence (13), and further study on the temperature variable is presently under way.

CURRENT STATE OF COLD WEATHER EARTHWORK PRACTICE

Since the literature on this subject is quite limited, additional information was sought via questionnaires to state and provincial engineers and contractors. The response was very gratifying.

Northern United States

The practices of the states in the area of significant frost were compared (13), and found to vary widely. Some of the variation can reasonably be assigned to differences in climate and in the predominant nature of the surface soils. An abbreviated summary of cold weather practice is presented in Figure 3.

Excavation and Placement

Excavation of any soil frozen to limited depths is generally viewed as a practical operation. Ripping along a grid pattern, followed by loading into conventional rubber-tired scrapers is the most common method.

Rock excavation can be carried out in about the same manner as in warm weather, while peat excavation is advantaged because access to these deposits is improved by ground freezing.

Excavated rock, reasonably dry sand and gravel, and peat can be placed in the same locations and by substantially the same methods as for normal season construction. However, the disposition of most frozen soil is limited. As illustrated in Figure 4, it can be: (a) wasted,

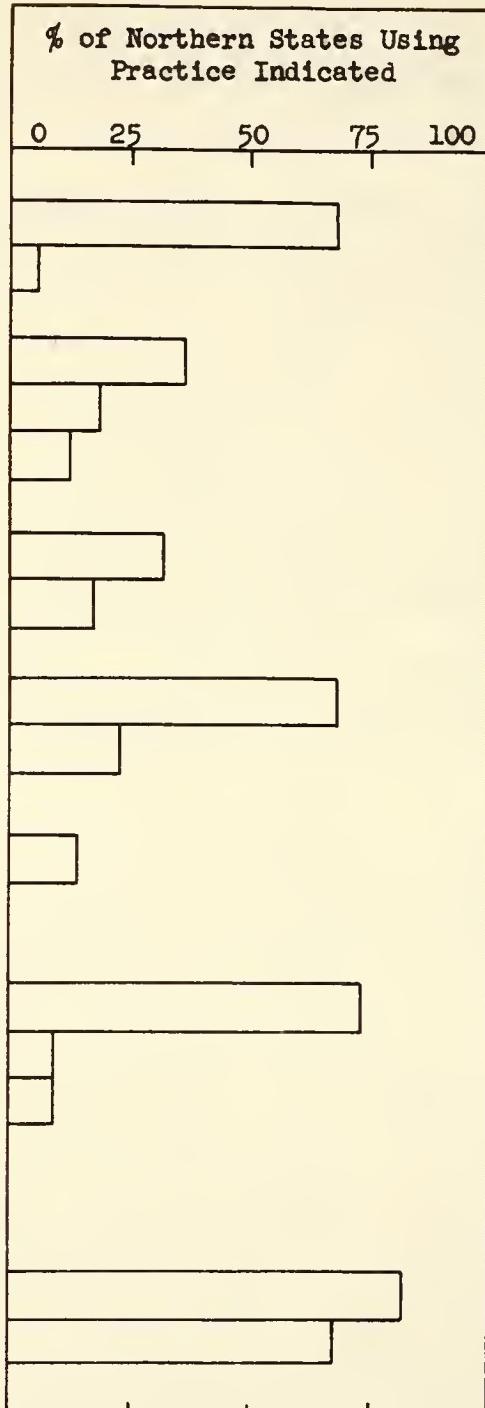


FIGURE 3. State of Winter Earthwork in the Northern U. S.



(b) stockpiled for use after thawing and draining, and (c) used in non-critical portions of an embankment section, i.e., outside a limiting slope line (say 1:1), or in berms. The reader will recognize that the disposition in item (c) corresponds to that of inferior unfrozen material (9).

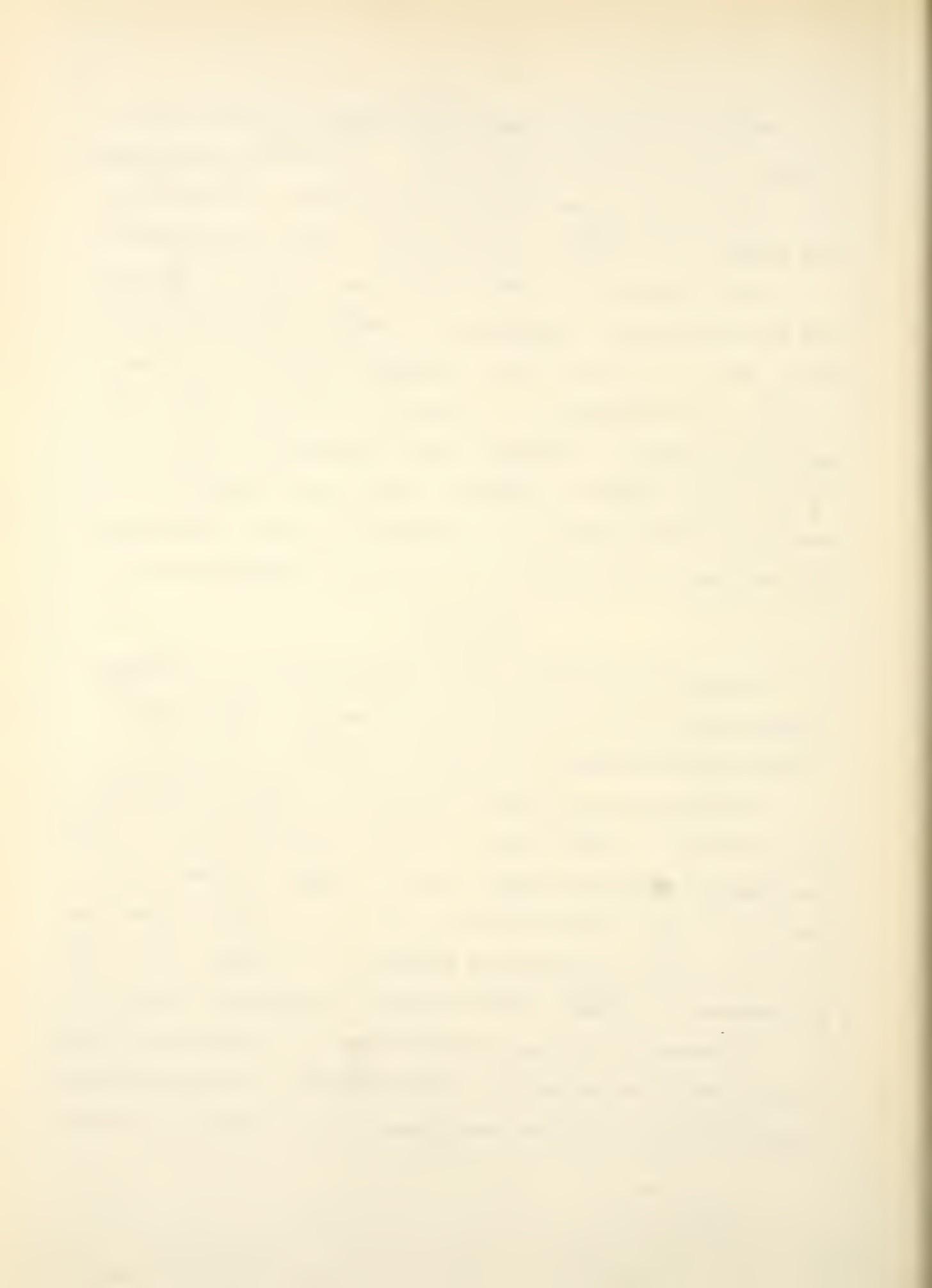
Once the frozen crust has been excavated and disposed of, attention must be directed toward the prevention of freezing of the underlying material, until it can be excavated, placed and compacted in fill. The primary rule is to minimize the area exposed to freezing, as well as the time of such exposure. Accordingly, active excavation and compaction areas are kept small. The state of Michigan reports use of a "ramp" placement and compaction method (Figure 5), which can limit the extent of an overnight or week-end freeze of the exposed layer of a partially completed embankment.

Compaction

Adjustment of the compaction water content is a much more difficult operation in cold weather, which means that compaction needs be accomplished at about the natural water content of the excavated soil.

One might expect natural water contents to be higher in the winter and spring than in summer and fall. The authors used reports of subsurface investigations for portions of the Interstate system in Indiana to study the values of natural water content. Projects were selected to cover many of the physiographic subsections of the State, and to produce a good seasonal distribution. The samples examined were those of material to be used in fills.

The standard AASHO optimum moisture content was either known or estimated for each sample, and natural water contents expressed as deviations from this value were plotted versus the date of sampling (13). Most moisture values



Frozen Soil if Necessary

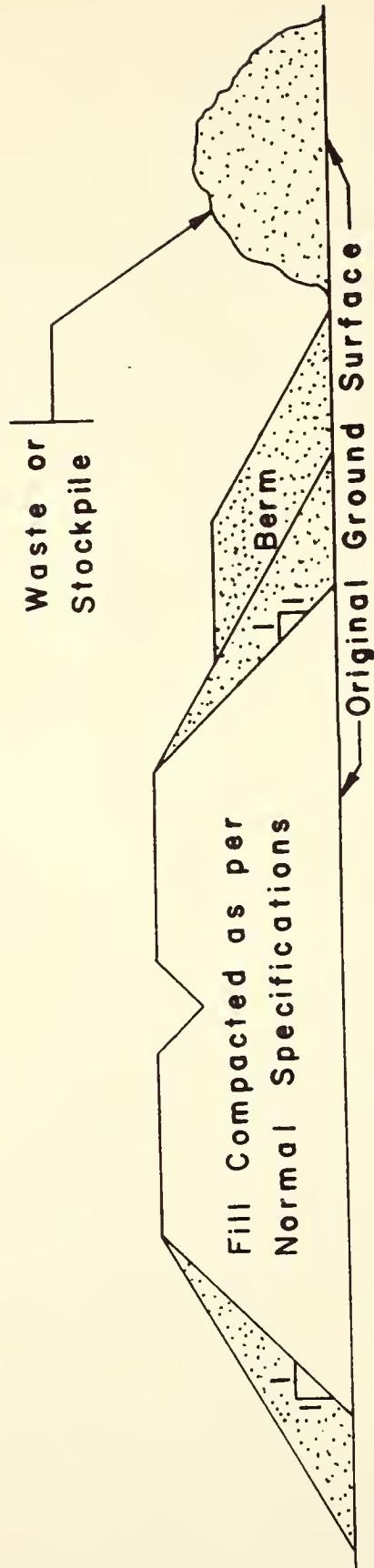
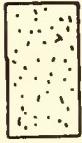


Figure 4. Locations Where Frozen Soil Can Be Used Without Detimental Effects

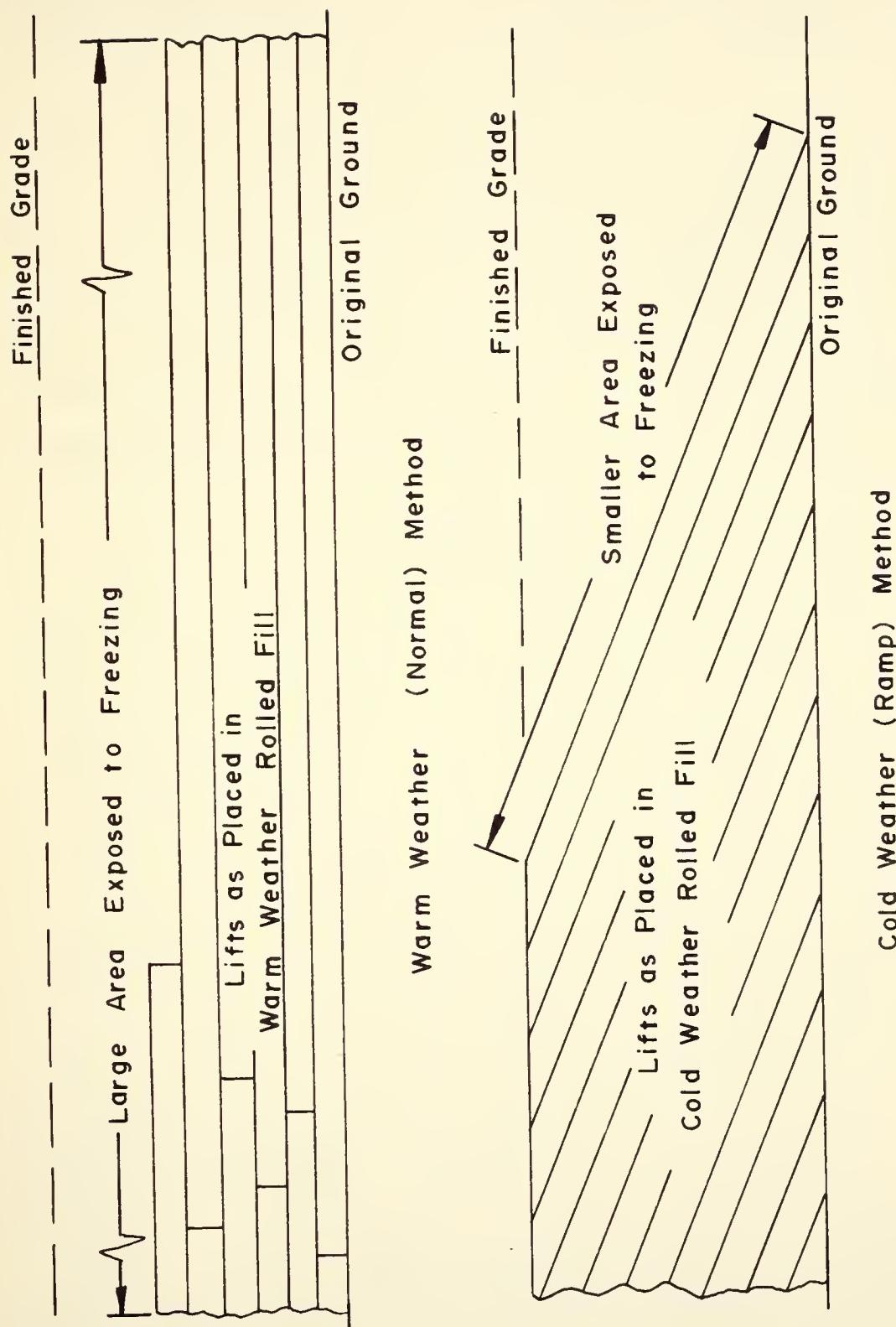


Figure 5. Embankment Profiles, Warm Weather vs. Cold Weather Lifts in Rolled Fills

were on the "wet side", but no seasonal trend was distinguished. About 23 percent of all moisture values were within $\pm 2\%$ of the standard AASHO optimum.

Granular soils can probably be adequately compacted even when frozen. If the material is placed as frozen chunks, it can effectively be disaggregated by rolling (vibratory smooth wheel and grid wheel rollers were cited in the review of practice). On the other hand, it is important to monitor both depths of freezing and in-situ moisture contents for those fine grained deposits planned for cold weather excavation and compaction. Both the compaction specification and the selection of the design section must be amenable to low temperature and (probably) wet-side compaction.

Canada and Alaska

These questionnaire responses cited several practices which supplement those reported for the Northern States. The cold season is used to build access roads in swampy areas...taking advantage of the improved mobility of equipment on the frozen ground. Once opened, borrow areas may be worked around-the-clock to circumvent surficial freezing. Embankments may be raised to within five feet of the subgrade level and left to be finished in the next warm season. One province has tried alternate embankment lifts of frozen fine grained soil and frozen granular material. The latter technique is analogous to alternate dry and excessively wet lifts in warm weather construction (4). Such embankments are compacted as thoroughly as practicable when placed, but are allowed to thaw and settle in the spring and summer before construction of the pavement.

Scandinavian Countries

The authors were particularly impressed by the content of a Swedish

report entitled "Eliminating Seasonal Variations in Road Construction" (2), and had it translated in part. Due to a combination of political, economic, and geographic factors, the art of cold weather highway construction is relatively advanced in Sweden.

Data are organized with respect to four climatic zones, and these zones correspond in terms of temperature and snowfall to the U.S. areas shown in Figure 6. The relative costs of many constructional operations are tabulated (2, 13). In the absence of first hand information, these tables, used in conjunction with a climatic correlation like that of Figure 6, permit prediction of the increased costs¹ of cold weather construction in the U.S.

Reference (2) further presents total construction project cost comparisons, assessing some of the major benefits which accrue because of the cold weather activity, and balancing these against experience relative to unit costs in the various seasons and geographic zones. Table 1 shows a net cost advantage for cold weather work of about 5 to 15% of the total construction cost. Two items of planning are implicit in the benefit: (a) the project length is great enough to encompass a wide variety of earthwork operations, and (b) the various operations are carefully scheduled so that each is begun at a time which is as optimal as can practically be arranged.

ECONOMIC FEASIBILITY IN NORTH AMERICA

With the encouragement afforded by a review of the current state of the art of cold weather earthwork, this study sought to be definitive about

1. The increase may be quite small (rock blasting, loading and crushing), or costs may even decrease, as in the case of peat excavation.



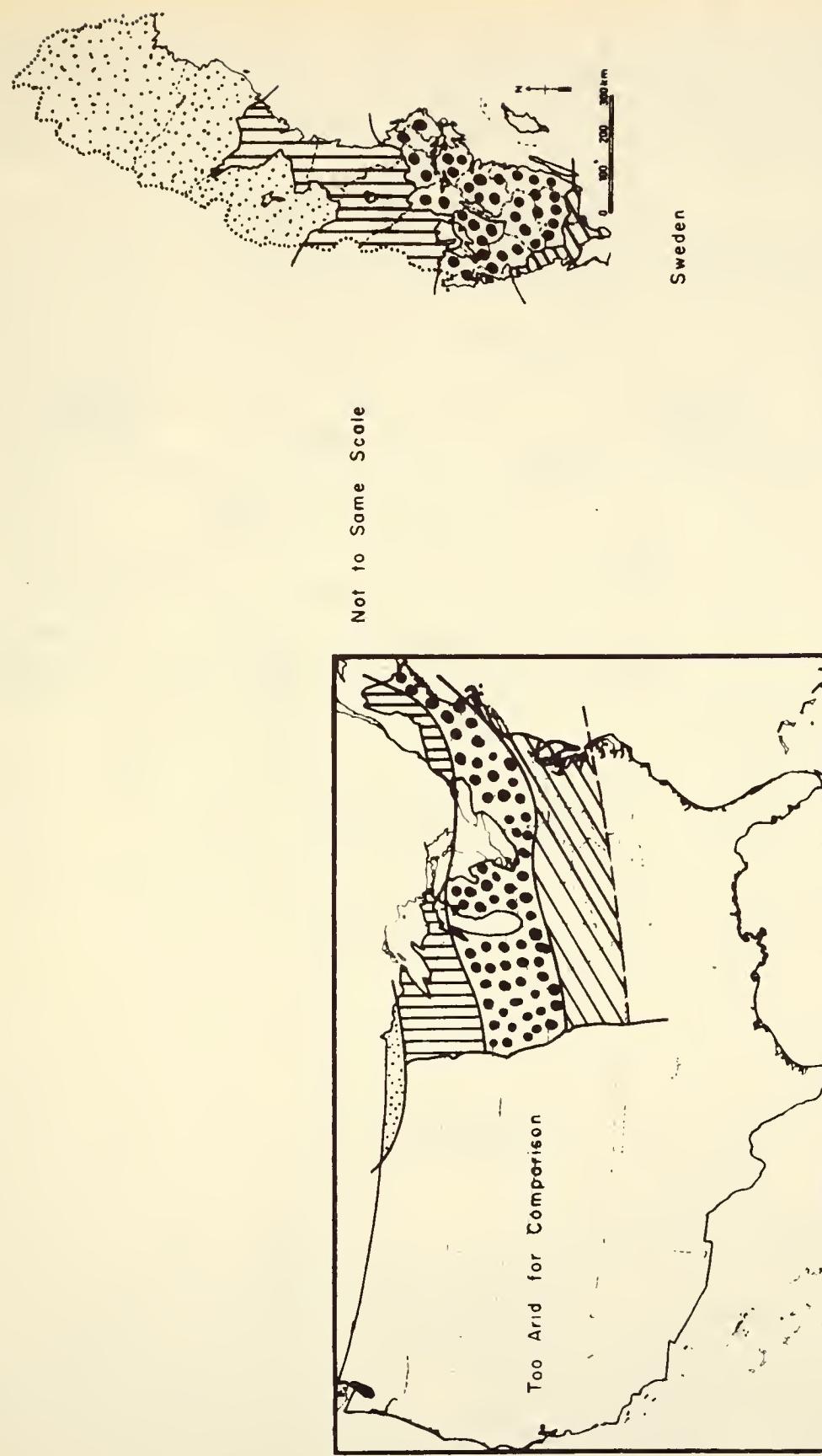


Figure 6. Areas of Sweden and the United States Having Similar Climates



Table 1

Summary of Cost Changes Caused by Different Construction Seasons

Times during which construc- tion proceeds	Nature of cost	Central Sweden	Upper Northern Sweden
Summer and Autumn only	Total cost of project	100%	100%
Year round, with steady employment of labor	Cost of project, incl.:		
	A. Increased costs for operations started at most suitable time	+ 6%	+ 12%
	B. Reduced costs for		
	1. elimination of sus- pension and resumption of work	- 3%	- 6%
	2. better exploitation of contractor's re- sources	- 8%	- 14%
	3. better exploitation of employer's re- sources	- 1%	- 2%
	4. lower interest char- ges for employer	- 1%	- 4%
	Total costs	93%	86%
	Maximum increase due to starting of operations at less suitable time	+ 3%	+ 7%

the kinds and magnitudes of its benefits. The focus was upon Indiana, but the general conclusions should reasonably apply to any part of the frost zone in North America.

While the weighing of economic benefits against increased cold weather operational costs is a necessary test, it is not a sufficient one, since there are human benefits over and above those reducible to economic terms.

Benefits are of two interrelated types: (a) those which result from an earlier completion date, and (b) those which accrue from reduction (or even elimination) of the seasonal interruption in construction.

The implicit difficulties of cold weather earthwork mean that one month of such activity will reduce the time required for project completion by only a fraction of a month. This fraction was assumed as $\frac{1}{2}$... working 2 winter months will advance the completion date by 1 month.

The economic benefit model which follows is a simple linear one, i.e., benefits are simply summed, without consideration of interactions.

Benefits of Earlier Project Completion

Construction costs will undoubtedly continue to rise in an inflationary drift. This trend can be reduced to a monthly rate (MID), and applied as follows:

$$(MID)(AC)(N_{RT}) = \text{Benefit}$$

where

AC is the annual cost, and,

N_{RT} is the number of months that project completion is advanced.

Earlier completion can also reduce the interest charges on money borrowed by the contractor to finance his operation. An important

factor is the time lag between contractor expenditures and payment for completed work. For purposes of sample calculations, this lag was expressed as one-fourth of the annual construction cost. Reducing interest charges to a monthly basis (MIC):

$$(MIC) \left(\frac{1}{4}\right) (AC) (N_{RT}) = \text{Benefit}$$

where all terms have been previously defined.

Inserting values of (MID) = 0.25% and (MIC) = 0.58%, the total benefit accrued through reduction in inflated costs and interest charges is 0.40% of the annual construction cost for each month that project completion is advanced.

A second class of benefits apply to the highway user, in that the new facility is both more safe and convenient than the highway mileage effectively replaced by it. For example, on completed sections of the Interstate System the fatality rate is only about one-third that on older highways in the same traffic corridors (11). With an average daily traffic (ADT) of 15,000 (1), there is a reduction in the fatality rate of 0.40 per mile of new Interstate per year. Following a simple expedient of pro-rating all accident costs on the basis of fatal accidents (1), and using national values of 49,000 deaths and \$8,900,000,000 in costs (12), the realized annual economic benefit is \$73,000 per mile of new Interstate. A one month advance in availability of the new facility would reduce accident losses by about \$6,000 per mile.

There are travel time delays incident to the existence of construction areas, since vehicles must continue on the old route and/or follow special detours. The economic detriment of such delays is of course greater in and around urban areas. Assume that 5,000 persons are delayed

5 minutes per day. With the value of travel time taken as \$0.86 per hour (1), a loss of \$10,700 per month is incurred. In addition, where construction activity requires rerouting of high traffic volumes, accident costs will rise well above the average values previously cited.

Benefits of a More Continuous Construction Operation

These benefits relate to three resource categories: labor, contractor, and highway agency.

The non-supervisory persons normally engaged in earthwork operations undergo a seasonal layoff, and either enter secondary temporary employment or qualify for employment compensation. In Indiana (5) the potential benefit of an added month of construction activity would be about \$175 per month (unemployment compensation not paid) per worker.

A part of the wage differential between northern and southern workers can logically be assigned to the smaller number of months of regular employment in the north. Assume that one-half of the wage differential can be so ascribed. For Indiana, as compared with the southern states (14), this is about \$50 per month per worker. If the northern worker is employed only part of the winter, this value must be reduced proportionately. In principle, and over the long run, cold weather construction would reduce the wage differential between locations of severe and mild winters.

Contractor resources of supervisory and professional personnel and capital equipment must be maintained year round, whether or not they are in effective use. Swedish experience (2) shows a benefit of 2% of the annual project cost for each month that suspension of activity is avoided. Further, if the construction function can be carried out around-the-calendar,

an additional benefit of 3% of the annual cost will accrue through elimination of the expense of suspending and resuming work.

Questionnaire responses from contractors in the south and southeast (13) reinforced the contention that large benefits can be incurred by contractors able to reduce or to avoid totally the seasonal suspension of operations. It was further stated that employer-employee relations were significantly improved when the seasonal layoff was eliminated.

A number of the points made with respect to contractor resources are equally valid for the resources of the state highway agency...particularly the construction division. Personnel would not need to be shifted to secondary functions during the winter, but could continue to be used in their areas of primary interest and competency. Once organizational adjustments were made, it is estimated (2) that a saving could be realized which amounts to $\frac{1}{4}\%$ of the annual project cost for each additional month of cold weather activity.

Table 2 summarizes all economic benefits which have been stated to accrue, for a case where the elapsed calendar time for project completion was reduced one month by undertaking two extra months of cold weather earthwork. The decision to undertake cold weather activity on a given highway project would be economically justified when the sum of benefits outweighs the predicted increase in cost of field operations.

Table 2

**Summary of Economic Benefits Derived from Finishing One Month
Earlier by Working Two Months Longer**

Source of Benefit (Conditional Assumptions)	Benefit as % of Annual Cost of Urban Project Unless Otherwise Stated
A. Less Inflation and Interest	0.40%
B. Reduced Accident Losses	\$6,100/mile
C. Reduced Construction Area Delays (5,000, 5 min. delays/day)	\$10,700/month of earlier finishing
D. Reduced Unemployment Compensation (4 1/3 weeks/month)	\$346/worker
E. Reduced Wage Differential ²	\$24 ($\frac{N_w}{N_I}$)/worker
F. Better Contractor Resource Utilization ³ (Conventional season was 8 months/year)	4%
G. Better State Resource Utilization (Conventional season was 8 months/year)	1/2%

1. Rural project figures would be the same except for a reduced value for (C).
2. ($\frac{N_w}{N_I}$) is ($\frac{\text{no. of weeks total working season planned}}{\text{no. of months workers were previously inactive}}$)
3. Bonus benefit if working 12 months/year...3% of annual cost of project, should be added.

SUMMARY AND CONCLUSIONS

1. The present state of the art of cold weather earthwork was reviewed for the northern U.S., Canada and Alaska, and the Scandinavian countries. This experience provides a substantial base for further controlled experimentation.

2. An assessment of the technological deterrents to cold weather earthwork was made, with emphasis upon the degree of difficulty afforded in Indiana.

3. The benefits to be derived from an earlier completion date and/or more continuous operation were categorized as to: (a) the highway user, (b) the labor resource, and (c) contractor and state highway organizations.

4. The sum total of the findings is encouraging, and it is likely that year-round earthwork is both economically and technically feasible for many highway projects in North America.

5. To advance the state of the art, a three-pronged research effort is recommended.

- a. An important part of the economic justification of cold weather earthwork lies in the earlier availability of a safer and more convenient use facility. These benefits need to be quantified as to magnitude and distribution among various classes of users.
- b. It is also contended that year-round utilization of the resources of the firms doing construction, as well as agencies exercising engineering control over the construction, produces economic benefits. The magnitude and distribution of these gains can be accurately assessed only by detailed studies of the organizational setups and operational systems of said firms and agencies.

- c. The excavation, placement and compaction of soils at low temperatures and high moisture contents are effectively discouraged by current state specifications. In order to provide a rational basis for liberalizing the specifications, both laboratory and field experimentation are in order. The laboratory phase would quantify the effects of low temperature and high moisture on soil properties and characteristics, and the field phase would test the performance of real highway sections in which the modified procedures were followed.

ACKNOWLEDGMENTS

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The writers appreciate the advice on construction methods and economics given by Dr. J. A. Havers, Associate Professor of Civil Engineering, Purdue.

Numerous highway department engineers and members of highway contracting firms promptly completed questionnaires directed to them, and thereby contributed substantially to the completeness of the study.

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